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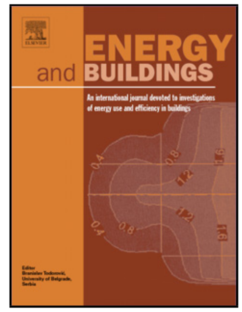

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A Study on the Proposes of Energy Analysis Indicator by the Window Elements of Office Buildings in Korea

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ABSTRACT

Recently, the window area ratio of buildings has increased but the thermal insulation performance of windows is lower than the wall. Therefore, many studies have been carried out to reduce this heat loss. The Republic of Korea policies and guidelines for windows do not consider the optical and design elements of windows because it is more important to the insulation performance of windows. This paper proposes the supplement point of the Korea's polices and guidelines regarding windows through a comparison of Korea's polices and guidelines for windows, checks the variation of the energy consumption of buildings through the variation of the window elements, and proposes an energy analysis indicator for the Republic of Korea's situation. This study confirmed that the variation of the window elements affect to energy consumption by previous studies to consider in window design according to the policies and guidelines. The window elements were divided into performance elements of the windows and architectural/equipment plan element. By analyzing the energy consumption by changing the element, this study confirmed the variation of energy consumption by using the COMFEN4.0 simulation tool. This paper proposes an actual Energy Analysis Indicator in the Republic of Korea.

Keyworlds : Window elements, Energy consumption, SHGC, WWR(Window wall ratio), COMFEN

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1. Introduction

The world regulates carbon dioxide emissions to help solve the energy crisis. Accordingly, the Republic of Korean government announced 'A low-carbon, green growth' aim to be 7th in the word in 2020 and 5th in the world by 2050 [1]. The government proposes a detailed policy :「Building Energy Conservation Design Standard」 about 「Energy-efficient Buildings」 among the many policies for energy saving in the architectural field. This policy is applied to new buildings and requires existing buildings to submit a building energy-saving plan [2]. The government has made significant efforts for building energy-saving. The WWR (Window-Wall Ratio) is increasing because the curtain-wall method is fashionable for reasons of view and age-flow [3]. Generally, an increased WWR results show an increased heat loss of buildings because the window has higher heat loss than the wall. The policy limits the thermal insulation performance to a limited WWR and proposes standards in policies and guidelines of window design of the Republic of Korea. On the other hand, the optical performance and placement by orientation was not considered in detail.

A previous study examined the window element for decreasing the energy consumption of buildings by evaluating the energy consumption of buildings. Hung-Wen Lin considered various elements (inter-heat, skin insulation, efficiency of boiler, etc) when examining the building energy and studied the WWR and type of windows affecting the building energy consumption [4]. Jinghua Yu used eQUEST, and examined the low-energy envelope design on a hot summer and cold winter zone in China. This study examined the effects of selected elements, such as WWR, type of window and shading, on energy consumption, and confirmed the electricity consumption of heating and cooling according to the variations of these elements [5]. Steinar Grynning confirmed the heat loss factor in buildings to predict the energy consumption of buildings because the performance of windows and the elements of the architecture have a complex relationship. A previous study examined the heat loss of windows using three methods to calculate the heat loss of office buildings [6]. These studies predicted the energy consumption of buildings and confirmed the window element as a way of reducing the energy consumption.

Many studies have confirmed the effects of the energy consumption of buildings by the variation of windows. T. R. NIELSEN reported a diagram of the different performance of windows by U-Value and G-Value(Total solar energy transmittance) [7]. Carlos E. Ochoa considered the element of windows for energy consumption and optical comfort. In particular, this study proposed the result that considers the side of energy consumption and optical comfort regarding the WWR. They confirmed that the WWR has a significant effect on energy consumption and optical comfort [8]. Mari-Louise Persson confirmed the changes in energy consumption according to the WWR, orientation and glazing type in a low energy house. Gul Koclar Oral compared many types of windows to identify a suitable window in terms of building heating [10]. J. Karlsson proposed a simple model to confirm the energy consumption by a variation of the window elements. The energy of windows was calculated in terms of building energy consumption by solar radiation gain and heat loss [11]. Therefore, many studies have performed quantitative analyses of the variation of energy consumption according to the variation of the window elements.

Energy consumption analysis of various windows, and a study on the local and actual situations are being carried out to consider their effect on buildings according to climate or region. M.K Urbikain examined a window energy rating system from Spain. A Window Energy Rating System (WERS) provides a simple, approximate method to compare the energy performance of various windows as well as determine the different potential savings for a range of weather conditions. The Window Energy Rating System was proposed for residential buildings in Basque Country, which is expressed in kWh/ (m^2 year), two method for the calculation. This considers the solar gain that is essential from a building-heating standpoint. Different windows can be compared and their relative heating energy savings for a reference building can be estimated using a simple equation [12]. Cheng Tian simulated a Typical office building in Hong Kong using WERS. A generalized WERS that considers all the primary influence factors was presented for a more realistic energy evaluation of typical office buildings. An application example showed that the algebraic WERS derived from the simulation results can be used easily for the optimal design of windows in buildings similar to a typical building [13]. Smar Jaber examined thermal and economic windows design in three climate zones and proposed a thermal model and economic model from the results of zones by the WWR and type of window [14]. Xing Su confirmed the effect on the environmental performance optimization of the WWR for different window types in the hot summer and cold winter zone in China in terms of the LCA(Life Cycle Assessment). This study can be a more accurate LCA prediction to consider the window element (WWR, orientation, glazing type) on LCA analysis in China [15]. J. W. Lee using building simulation modeling, evaluated a range of window properties, such as the U-Value, solar heat gain coefficient (SHGC), and visible transmittance (VT), with different window wall ratios (WWR) and orientations in five typical Asian climates: Manila, Taipei, Shanghai, Seoul and Sapporo [16]. Through these studies, they provided the energy consumption analysis of the window elements according to the actual climate and region.

Yalcın Yasar used an energy simulation software to determine the effects, including the building energy consumption and economy, of different types of glazed units (solar control, heat conservation and solar control, and heat conservation glazed units) used in high-rise residential buildings located in the moderate-humid climate regions in Turkey [17]. M. Bojic examined the energy performance of multiple windows in a residential high-rise building in the hot and humid climate of Hong Kong [18]. K. Hassouneh examined the variations of the type of glazing using eight types of glazing (clear glass, types A, B, C, D, E, F, and G) to determine the most appropriate in each direction. In addition, the orientation of the window is changeable in the four main directions (N, S, E, and W). The area of glazing was also varied in a different orientation to determine the effects of the window area on the thermal balance of the building. The results showed that if energy efficient windows are used, the flexibility of choosing the glazed area and orientation increases [19]. As above, studies of actual buildings with specific examples have been carried out.

In a Korean study, Yool Park examined the energy use impacts of the SHGCs of windows in a detached house. This study confirmed the following result. The energy consumption of a building is decreases with increasing u-value of a window but the energy consumption variation by SHGC was different. This study revealed a problem of the policies of energy saving based on the U-Value in the Republic of Korea [20]. Another study proposed a typical WWR of Korean houses, and confirmed that the variation in energy consumption by the variation in the U-Value is larger than that caused by a variation in the SHGC [21]. In Korea, it is difficult to predict the energy consumption because the studies are limited to the thermal insulation performance and do not consider the optical performance. Yong-Sang, Yoon examined the Optimal Window Applications According to the Window Ratio (WWR) and SHGC in Office Buildings. In this study, a building energy simulation was conducted, and the influence on the energy performance was analyzed according to the WWR, Visible light Transmittance (VT), Solar Heat Gain Coefficient (SHGC) and U-Value. When the heat load and radiation were considered, the window area ratio was found to increase and the increase in energy consumption was not proportional. In the same WWR, much larger cooling energy consumption than heating was confirmed from the effects of the variation of SHGC. In a low SHGC, it was confirmed that the energy consumption is smaller at the maximum WWR than minimum WWR. This study proposed that the optical performance element and suitable WWR considered before the window design [22]. From the result, a study of the effect of the window element for the energy consumption of a building is being carried out but the government and guidelines proposed only a thermal insulation standard and did not consider complex elements. This study confirmed that the government and guidelines need to consider complex window elements because they have a complex effect on the energy consumption of buildings. Therefore, actual applications by policies and guidelines will decrease the energy consumption of buildings with a raised WWR.

In this study, the window elements were considered in window design through a comparison of the policies and guidelines for windows in other countries. From the results, the complement points of policies and guidelines in Korea were proposed. This study confirmed the effects of the window elements on the energy consumption. An energy analysis indicator according to the window elements in an actual environment in Korea is proposed.

In this study, the scope of the study is as follows: the policies and guidelines regarding windows in Korea and other countries were compared; the data was divided into the performance element of the windows and the architectural/equipment plan element. An energy analysis indicator was also proposed for the Republic of Korea.

In this study, the method in the study was as follows: the policies and guidelines for windows in Korea and other countries were compared; an energy simulation on applying a complex performance element of the window and architectural/equipment plan element was performed; and effects on the energy consumption of a building was confirmed by analyzing the heating and cooling energy consumption.

To propose the energy analysis indicator for the Republic of Korea situation, this study analyzed the energy consumption of buildings by the variation of the window element that considered to the policies, institution and guideline. This study proposed an energy analysis indicator.

2. Analysis of the policies and guidelines for windows in Korea and other countries

2.1 Status of the Policies and guidelines for windows in other countries

The「Energy Star (Homes Builder Option Package)」 was enacted by the EPA and DOE in the USA in 2010. This aim of the program was to achieve a 30% saving on the building energy-related costs. The targeted residential buildings and evaluation element is the insulation performance of window and WWR. The insulation performance should be 'Energy Star' certified or the product should satisfy the performance requirement of the SHGC at the climate zone. The WWR was distinguished at 10%, 12%, 14% [23].

「The State of Minnesota Sustainable Building Guidelines」 was enacted by the 'Center for sustainable building research, University of Minnesota'. The evaluation element included the amount of sunshine, view and thermal comfort. The goal was a 30 % saving in the energy consumption of buildings. The new construction or remodeling of residential and non-residential buildings was targeted. The amount of sunshine must be that the minimum rate of daylight shall not be less than 1% in 75% of the floor area, Views should be obtained at 20 feet and within a 10° horizontal and vertical gradient. The thermal comforts proposed a standard for temperature and humidity [24].

「LEED NC V3」 was published by 'Green Building Council' of USA, which offers productivity enhancement of the building user and comfortable environment, the purpose is to connect the indoor space and outdoor spaces through the introduced appropriate position to natural light and view. The evaluation elements are the amount of sunshine, view, thermal comfort and lighting control. New construction or remodeling buildings of non-residential buildings are targeted. The amount of sunshine in daylight can be more than 75%, brightness (> 250lux) or more than 2% of the Daylight Factor. The views consider Vision Glazing. The thermal comfort can be the individual temperature control of 50% of building users, and should satisfied the ASHRAE Standard 55-2004. The lighting control system of buildings must be individual control to a minimum of 90% [25].

「Alaska-Specific Amendments to the IECC 2009」 proposed the U-Value and SHGC of windows, which is acceptable for each zone according to the climate in the Alaska area. Alaska was organized into zones 6, 7, 8, and 9 according to the climate-specific area of USA. The zone is distinguished by the different thermal performance and 0.45 is the same as the zone by the SHGC [26].

「Advanced energy design guide: Small office buildings」 is one of the guidelines of the ASHRAE to achieve a 30% decrease in energy consumption as a design guide. The targeted 20,00ft^2 was limited to small office buildings, which was configured to present quantitative indicators of the insulation performance, SHGC, VT, WWR by climate. [27]

「SAP2009」 evaluated the energy performance for the new construction and existing buildings, this is a system that mandates an indication. SAP2009 was applied irrespective of the different region from the USA System of regions to apply different standards. The system was applied to limited residential buildings, and the insulation performance, VT and WWR, were evaluated [28].

「Approved Document L.」 is one of the UK building regulations, and shows the policies on the insulation performance, WWR by residential and non-residential buildings. In particular, in residential buildings, the insulation performance value was applied to the differently shown characteristics [29].

「Energy Conservation Regulation (EnEV)」 is the building regulation of German to reduce primary energy consumption. The main contents is the regulation of insulation performance, HVAC, hot-water, lighting and etc. about the residential, non residential, new building and existing building. The regulation is provided the insulation performance of window and the lighting control of residential & non-residential buildings[30].

「Passive design tool kit」 defined the passive design of building, and was used as an indicator of minimum energy consumption to ensure the comfort of the guidelines. This was developed by engineering companies and architects, and targeted residential buildings and commercial buildings. Generally, the use of high-performance windows is recommended, and the guidance from the WWR and shading installation is emphasized [31].

「Passive homes Guidelines for the design and construction of passive house dwellings in Ireland」 is a Passive house design guideline for the energy-saving policies of the Irish government. To improve energy efficiency of buildings, the purpose is reduce greenhouse gas emissions through the use of renewable energy. The target includes the new construction of passive houses in residential buildings, and the evaluation elements are the insulation performance, VT and Orientation [32].

「DCGREUH 1999」, as a part of building codes in Japan, regulated the insulation performance of windows and SHGC, according to the climate. The climate was divided into 6 zones, 'Climate zones 1' to 'Climate zones 6', and applied differently [33].

「Energy Conservation Building Code 2007」, which is one of the Indian building codes, proposed the value of the insulation performance and SHGC regarding the WWR according to the climate. The features of the guidelines provide a method for alternative ways of relieving the guidelines when they do not meet the guidelines at the level of need. In addition, this study proposed a different method for analyzing the insulation performance(U-Value) and SHGC, than the simple regulation of various alternatives that can be selected [34].

The results confirmed the policies and guidelines for windows (Appendix 1). The most significant item is the U-Value by the insulation performance, confirming that the most important performance element of a window is the insufficient insulation performance compared to the walls. The WWR was considered. These were limited to the wall ratio because the area shows larger heat loss and solar heat gain according to the building type. The policies and guidelines proposed the SHGC according to the region and WWR. This is important for the SHGC because the solar heat gain has a significant impact on the energy consumption of buildings. In addition, the characteristics of the occupants considered the VT, View, thermal comfort and amount of sunshine.

2.2 Status of the policies and guideline for windows in Korea

This study confirmed the difference of the policies and guidelines between Korea and other country. This study confirmed the notes for the energy analysis indicator at the actual situation in Korea.

「Building Energy Conservation Design Standards」 was published by the Ministry of Land, Transport and Maritime Affairs and was enacted on January 11, 2008. The purpose was to determine the building standard to mitigate the energy savings, the writing standards of the saving plan and what energy savings will be achieved in terms of the efficient energy management of buildings. Regulations will be applied to large sized buildings, such as apartment blocks containing more than 50 dwellings, welfare facilities, research institutes, hospitals, bathhouses, swimming pools, and large stores. The thickness of the wall must comply with the technical regulations and technical standards. As technology advances, the technical standards need to change. This applies to residential and non-residential buildings. The elements of the thermal insulation performance of windows, the air tightness performance and shading installation are regulated. The energy performance evaluation was carried out using the performance criteria. The evaluation system is a different a rating system that is classified as residential and non-residential. Through the energy efficiency rating, building standards to mitigate the benefits were given. The point of this standard was to determine if they were satisfactory by presenting the concept of the standard of the total annual energy use based on the energy consumption per unit and the individual performance according to the elements through a quantitative figure [2].

「The Construction Standard on Low-Energy Green House and Performance」 was published to provide an institutional-based. The purpose was to construct a green house through the construction standard and performance of low-energy green house to reduce the energy consumption and carbon emissions. The application range was limited to residential constructions. The target was an apartment block with more than 20 dwellings. The evaluation element was the performance and Air tightness of the window [35].

The purpose of the 「Innovative urban design guidelines for public buildings energy saving」 was to determine the design standard for recommended energy-saving buildings, such as a decrease in energy load and utilization of renewable energy in public buildings in an innovative city by 「According to the relocation of public institutions on urban construction and support innovative Special Law」. The application range is limited to public buildings. This guideline regulates the thermal performance, Air tightness performance and WWR. This guideline utilizes the design standard for the buildings of energy-saving and should comply with the Building Energy Conservation Design Standards [36].

According to Article 15 of 「Energy Using Rationalization Law」, the 「Energy efficiency equipment operating regulations」 notice from the Ministry of Knowledge Economy and manage energy management corporation was set up. Three programs were selected, 'Energy efficiency rating', 'High-efficiency equipment' and 'Standby power'. In this regulation, the grade of window applied to the buildings was selected according to its efficiency rating window set. This applies to "The Window set as prescribed 'KS F 3117', encounter outside air, sold in combination of a frame more than 1 ㎡ and glass, " and "Combined from the frame and glass or if the dealer assembly and construction by domestic manufactures guide". The test criteria and method were two types of physical tests and simulations. The physical test measured the performance according to 'KS F 2278'(insulation) and 'KS F 2292' (Air tightness). The simulation calculates the thermal insulation performance using the latest software (Window, Therm, etc.) from ISO 15099. ISO 15099 includes the U-Value calculation formula. The model and test of the window set are essential to a physical test when changing the material of the frame, opening the way, and window form. The simulation can be performed based on a physical test if the efficiency is changed by the specifications of the glass and filling. The Consumption Efficiency Level Index is expressed as 'R', which means the U-Value (W/㎡·K) [37].

「The Window Design Guideline for Energy-saving of Buildings」 was published the Ministry of Land, Transport and Maritime Affairs. The purpose of the guidelines is to allow a variety of designs to considering the energy performance in building design. This guideline confirmed the impact of the window design of office buildings to the energy consumption of buildings and proposed orientation, WWR, and types of windows in each region. In addition, it can be considered to calculate the energy savings [38].

「Green Design Seoul private buildings and public house design guideline」 was published by Seoul City Hall in February 9, 2010. The purpose of the guidelines was the Goals of 2030 Green Design Seoul and respond to the energy demands of buildings and climate change. The target is that all buildings submit their energy-saving plan. The evaluation is the thermal insulation, air tightness and WWR. In particular, other policies and guidelines proposed that the recommended level be a 'minimizing the north facing window area ratio' in WWR. On the other hand, these guidelines of Seoul have the characteristics that the proposed limiting values are like a 'rate of wall more than 40%' [39].

「Green Building Design Guideline for Low Carbon and Green Growth」 was published by the Incheon Metropolitan City in April 5, 2010. The purpose of the guidelines was low-energy building design for low carbon and green growth. In addition 'activation of the low-energy buildings using renewable energy (Solar, Wind, etc.)' and 'Zero Energy House realization by the presented Energy-independent future city' is also goals. The application range is buildings limited to apartment blocks with more than 50 dwellings and a floor area more than 3,000 ㎡ to submit an energy-saving plan. The evaluation items are the insulation performance of the window (U-Value), material (recommended double low-E glazing, double grazing, high air tightness), WWR, Orientation, and amount of sunshine. These guidelines also have benefits of the floor area ratio incentive by the EPI or Building Energy Efficiency Rating [40].

「Guidelines for low-energy eco-friendly Apartment House」 was published by Gangdong-gu office of Seoul city in March 2010. The purpose of the guidelines was to implement the Eco-Gangdong and sustainable administrative city by applying a large-scale reconstruction in Gandong-gu. The application range limited residential buildings in house construction and reconstruction maintenance businesses to the more than 300 house scale. The evaluation items are the thermal performance of the window and air tightness, WWR, amount of sunshine. The guidelines presented three options to Mandatory/Recommend/Option. This guideline can be mitigated through the consultation and review of Gangdong Building Council [41].

「Seongbuk-gu Low Carbon Green Design Construction Guideline」 was published by Seongbuk-gu in Seoul city in June 2011. The guideline's purpose is to induce the construction of energy-saving buildings in the design phase regarding public/private buildings. The application range is residential (public/private) and non-residential(public/private) buildings, which need to submit an energy-saving plan. The evaluation items are the thermal performance of windows, WWR. These guidelines describe the material and characteristics of windows. Double low-e glazing, triple glazing and high-Air tightness windows are recommended for outside windows in residential buildings. This is mandatory in non-residential buildings [42].

「Low Carbon Green buildings Design Guideline」 is published by Suncheon city in January 2011. The purpose of the guidelines is to provide a standard for energy-saving construction by reducing the energy load and apply renewable energy. Ultimately, this purpose is passive buildings with a minimal energy demand. The application range divided to residential and non-residential. The evaluation item differed according to the building type. The evaluations of residential buildings are the performance of the insulation (U-Value), material, characteristics, and Air tightness of the windows. The evaluation of non-residential buildings includes the performance of insulation, material, Air tightness, WWR, amount of sunshine and installation of Shading. This guideline recommends Low-E double glazing or more than triple glazing for windows [43].

Table 1 The Consideration Items of the Policies and Guidelines for Window

Table 1 shows the results of the policies and guidelines for windows in terms of the elements of the policies and guidelines. Similar to the policies and guidelines about window in other countries, the U-value is considered the most in the policies and guidelines in Korea. As mentioned earlier, the insulation performance is important and the WWR is considered. In addition to the guidelines in other countries, there are limited wall ratios, a proposed certain percentage of window area by the floor area and the recommended minimized window area facing the North.

The air tightness was also mentioned with the most demand in dwellings with more than 2 levels according to the KS F2292. The Air tightness goal is to improve the performance because the air tightness should be included in the construction problems. In addition, there are regulations to consider Shading, amount of sunshine, Orientation and etc.

2.3 Window Elements

This study examined the elements of windows by a comparison of the policies and guidelines for windows in Korea and other countries.

2.3.1 Performance elements of Windows

The elements of window have a huge effect on the building energy consumption because the window is installed to openings and has different properties compared to the wall.

(1) U-Value

The typical performance element is the U-Value. The U-Value indicates W/㎡·K, which is the unit area for heat transfer. The U-Value is the general indicator of the thermal performance of a structure consisting of a range of materials.

(2) Solar Heat Gain Coefficient (SHGC)

The SHGC is one of the optical elements, which shows the degree of solar radiation through the window is a dimensionless number. SHGC is an opposite concept to the Shading Coefficient (SC) and reflects the angle of incidence. This is an important element of a window like a U-Value.

(3) Visible light transmittance (VT)

The VT is the value of visible light of the ratio of transmission at glass in the radiation from the sun, and is a dimensionless number ranging from 0 to 1 [38]. The VT is related to the SHGC. In general, a lower VT means a lower SHGC, which mean that more solar radiation is blocked. Through glazing, the VT is important but the VT relative to SHGC is not considered. In addition, a low VT is more effective in reducing glare because of the increasing glare reduction.

(4) Air tightness

The air tightness is important to the performance of windows because this blocks the air flow causing a difference in the indoor and outdoor temperature of buildings. In particular, the windows and outer wall must be an integrated construction because of the broken unity of the wall. If it is not an integrated construction, air flow can occur as a result of the different pressures, which can cause heat loss. The method for the increasing Air tightness performance was applied to the windows as follows: difference in the opening way, increased air tightness, etc. The air tightness performance of the window shows amount of air flow by the different pressure at the window, and the unit of the Air tightness performance of windows is reported as ㎥/㎡ h [38].

2.3.2 Architectural/equipment plan element.

In the design of buildings, the performance and placement ad location should be considered.

(1) Orientation

The amount of sunshine is affected by the orientation. The designer of a window should consider the orientation of the window installed, which is reasonable. In a normal summer, the amount of sunshine at the east and west is small but the west requires a larger cooling load in the afternoon because of the afternoon sunshine. The south has a larger amount of sunshine but the solar radiation can be blocked easily by Shading.

(2) Window-Wall Ratio (WWR)

In Building Energy Conservation Design Standards, WWR (WWR = [Window area/(outside wall area + window area)]× 100) is determined to be 'The window area for the entire envelope except for the roof and the floor area'. The WWR is increased by the trend of a curtain wall because of its attractiveness. This increases the cooling load but decreases the heating load because of the season and solar radiation, which means that the proper WWR should be considered.

(3) Shading system

Shading is one of the methods for reducing the energy consumption of buildings while ensuring the view. The shading is divided into inside and outside shading. The ideal shading is to block solar radiation but achieve acceptable ventilation and view. In this regard, outside shading has more efficiency than inside shading. Inside shading leads to radiation between the shading and window so outside shading is more efficient because the outside shading blocks solar radiation before it reaches the window. The install option of the outside shading can be limited by high rise buildings or the characteristics of buildings. The design of the outside requires the azimuth of the sun, view, ventilation and maintenance to be considered.

(4) Lighting Controls (L.C)

The artificial lighting in offices is not actively controlled by the occupants. Therefore, lighting is used in areas of no occupants or in areas of sufficient natural sunlight which can increase electricity use. In addition, lighting energy can be used to assist in the cooling energy by acting as a cooling load. To solve these problems, a reduction in unnecessary lighting energy using daylight sensors installed into lighting equipment with a lighting control system is needed.

3. Analysis of energy consumption by the window elements

In order to the variation of energy consumption of the variation of window elements, this study analyzed energy consumption by simulation.

3.1 Standard buildings modeling and parameter settings

3.1.1 Standard building modeling

The propose of standard buildings and the performance standard were studied. On the other hand, the common performance standard derived process in Korea is unclear. As a result, this study introduced the proven process and selected a standard building. This study referenced the 'Windows for high-performance commercial buildings: Design guidance for offices Washington, DC (2011)' and proposed an analysis method for lighting/heating and cooling energy consumption by unit space modeling [44]. The COMFEN 4.0 and Facade design tool were used as the simulation tools.

This method revealed the energy demand and the best way according to the variation of the window elements at each orientation. This study selected the unit space to standard buildings and size of this unit space was 6 x 4.5 x 2.7m. This size is the result of research that considers the average commercial building by an analysis of the buildings. The gap between the columns of the building was 6m, the depth to the considering environment of light was 4.5m, and the height of room was 2.7m[45].

3.1.2 The Parameter settings of window elements

After selecting the standard building, the selected window elements were divided into the performance elements and architectural/equipment plan elements for an analysis of the variation of energy consumption according to the window elements. The performance of windows was divided into thermal performance and optical performance. The thermal performance was selected to U-Value to consider the insulation performance. This study selected five values proposed by the 「Energy efficiency equipment operating regulations」by Korea Energy Management Corporation, 1.0, 1.4, 2.1, 2.8, and 3.4(W/㎡·K), by considering the 'Grading standards of energy efficiency' [37]. The air tightness performance was not considered because it should be improved first and joints should be considered at the same time. The optical performance, VT and SHGC have a relationship. In previous studies, SHGC and VT were deal with and the SHGC was generally used. As a result, this study did not consider the VT and used SHGC. From the results of a previous study, this study selected 4 types, 0.2, 0.4, 0.65 and 0.75, to analyze the pattern of the variation [45]. Table 2 lists the type of window regarding the combination of performance elements. The architectural/equipment plan elements of the affecting window vary. The regional divides region into three: Central (Seoul), Southern (Daejeon) and Jeju by 「Building Energy Conservation Design Standards」 [2]. The orientation with the most impact on solar radiation through window selected four bearing. The WWR is four cases of 20%, 40%, 60% and 80%.

Table 2 Type of glazing

3.2 Simulation Condition

This study used COMFEN 4.0 by LBNL (Lawrence Berkeley National Laboratory) and simulated standard modeling. This tool is a facade design tool based on the Energy Plus engine and provides a systematic evaluation of various elevations. COMFEN 4.0 can model the fenestration facade to the number of windows, size, location, glazing, frame, outside shading. In addition, it can be compared using a range of facades. The facade can select the daylight controls and has the option of orientation of the buildings. The annual energy consumption (heating, cooling, fan, and lighting) and peak energy were analyzed by comparing the charts [46].

In this study, the number of windows, size and location were selected for COMFEN 4.0 HVAC in a Packaged Single Zone and the occupants, lighting and equipment schedule were considered. This study chose an office building as the standard building. Table 3 lists the simulation condition and schedule shown in Figure 1.

Table 3 Simulation Condition

Figure 1 Schedule of Simulation

3.3 Result analysis of energy consumption

3.3.1 Analysis of the energy consumption in the East direction of Seoul.

This study analyzed energy consumption in Seoul according to the advanced simulation settings for an analysis of the energy consumption by a variation of the window elements. Figure 2 presents the results of simulation in the East direction of Seoul.

Figure 2 The Result of Simulation in East direction of Seoul

Figure 2 (a) shown the annual energy consumption. The annual energy consumption was largest, 1045.9 MJ/㎡·yr, at a WWR of 80%, Type 16 (U-Value : 3.4, SHGC : 0.75). The consumption was lowest, 671.0 MJ/㎡·yr, with a WWR of 60%, Type 1 (U-Value : 1.0, SHGC : 0.2). Generally, the energy consumption increases with increasing WWR but it did not in the present case. In the case of type 1, the energy consumption decreased 2.8% when the WWR was increased from 20% to 80%. This confirmed that although the WWR increased and there was a low U-Value and low SHGC, the energy consumption decreased.

Figure 2 (b) shows the energy consumption of each WWR by SHGC in U-Value 2.1. In the case of WWR of 80% to 20%, SHGC 0.2 increased approximately 3% and SHGC 0.75 increased approximately 30%. At the same U-Value, the increasing degree of energy consumption was different.

The analysis result of the heating energy in the East direction of Seoul showed that when WWR increased from 20% to 80%, the heating energy consumption decreased by approximately 60% (U-Value : 2.1, SHGC : 0.65). With increasing SHGC and U-Value, the energy consumption increased by 8%, 11%, 11% and 9% in the case of WWR 20%. In addition, the energy consumption increased by 15%, 28%, 27% and 9% in the case of a WWR of 40%. In the case of a WWR of 60% the energy consumption increased by 24%, 51%, 51% and 48%. The energy consumption increased by 34%, 86%, 84% and 83% at a WWR of 80%. As a result, if a low SHGC in the case of all WWR, the increased heating energy consumption is relatively low. This result was shown Figure 2 (c).

The analysis result of the cooling energy in the East of Seoul showed that when the WWR was increased from 20% to 80%, the cooling energy consumption increased by approximately 60% (U-Value : 2.1, SHGC : 0.65). With increasing SHGC, the cooling energy consumption increased but the cooling energy consumption decreased from 1%~12% according to the U-Value.

3.3.2 Analysis of energy consumption in the South direction of Seoul.

Figure 3 shows the result of the simulation in South direction of Seoul. Figure 3 (a) present the annual energy consumption. The annual energy consumption was largest 877.8 MJ/㎡·yr when the WWR was 80%, Type16(U-Value : 3.4, SHGC : 0.75) and lowest at 586.7 MJ/㎡·yr when the WWR was 80%, Type 1(U-Value : 1.0, SHGC : 0.2) As with previous results, this result confirmed that although WWR increased the low U-Value and low SHGC decreased the energy consumption.

Figure 3 The Result of Simulation in South direction of Seoul.

Figure 3 (b) shows the energy consumption at each WWR according to the SHGC in U-Value 2.1. When the WWR increased from 20% to 80%, this study confirmed that the energy consumption decreased in the case of SHGC = 0.2 and increased in the case of SHGC = 0.75. Overall, at the same U-value, the energy consumption differs according to the SHGC

The analysis result of heating energy in South direction of Seoul confirmed that when WWR increased from 20% to 80%, heating energy consumption decreased approximately 68% (U-Value : 2.1, SHGC : 0.65). With increasing U-Value, heating energy consumption increased by approximately 14% (U-Value : 2.1□3.4, SHGC : 0.65) when the WWR was 20%. With increasing U-Value, heating energy consumption increased approximately 104% (U-Value : 2.1□3.4, SHGC : 0.65) when the WWR was 80%.

The heating energy consumption decreased with increasing WWR. In the case of a higher WWR, the heating energy consumption increased with increasing U-Value. The analysis result of the cooling energy of South-facing buildings in Seoul showed that the cooling energy consumption increased by approximately 112% (U-Value : 2.1, SHGC : 0.65) when the WWR was increased from 20% to 80%. With increasing SHGC, the cooling energy consumption increased but decreased with increasing U-Value from 1% to 15%. Through an analysis of the orientation in Seoul, this study confirmed that if a high performance and low SHGC window is used, the energy consumption will decrease with increasing WWR.

As a result, the change in energy consumption according to the variation of windows was not uniform as proposed by the policies and guidelines in Korea. Complex elements, such as the Orientation, WWR, SHGC, U-Value, should be considered.

4. Proposed Energy Analysis Indicator according to the Window Elements

The Energy Analysis Indicator of suitable situation in Korea is suggested. This section proposes the Energy Analysis Indicator according to the Window Elements.

4.1 Simulation Overview

To confirm the energy consumption by the variation of window elements, this study used the COMFEN 4.0 and determined the U-Value according to the standard of regional windows U-Value limit proposed by the 「Building Energy Conservation Design Standards」. The SHGC was selected by 24mm Low-e glazing. Through the above, this study determined the performance of windows (BASE) [2]. In this study, the shading and lighting control by 「The Window Design Guideline for Energy-saving of Buildings」 were considered [38]. CASE 1 is the base case. The WWR and Window systems were applied to Seoul for the case of no control, and energy analysis was performed. CASE 2 was CASE 1 with added Shading. CASE 3 was CASE 1 with added Lighting Control (L.C). CASE 4 was CASE 1 with added shading and lighting control. The U-Value was selected by the 'Table U-Value of regional building Part in「Building Energy Conservation Design Standards」[2]. Table 4 lists CASEs and Glazing Type of Simulation.

Table 4 CASEs and Glazing Type of Simulation

The selected exterior shading and fixed type were used to combat the influx of sunlight. This simulation applied horizontal shading to the South and North. The vertical shading was applied to the East and West. The office buildings used unnecessary lighting energy consumption resulting in higher lighting energy consumption than residential buildings and active lighting control by the occupants is difficult. If lighting control at appropriate illumination is used, the lighting energy consumption and heat load of the lighting equipment can be reduced. In this study, the lighting control was 'Stepped Control'. This method is the control of indoor lighting by several steps of indoor illumination[46].

4.2 Analysis of the simulation results

A simulation of region, orientation and case was performed to analyze the energy consumption by the variation of the window elements.

4.2.1 Comparison of the energy consumption according to the type of WWR and window type.

To compare the energy consumption by the type of WWR and window type, this study analyzed the results of CASE 1. In this case, the shading and lighting control were excluded. With increasing WWR, the energy consumption increased in the window with same performance. This study confirmed that the difference in energy consumption increased with increasing window performance. If the WWR is greater, the energy consumption is affected more by the SHGC than the U-Value. Figure 10 shows the daylight illuminance according to the WWR and glazing type in the South facing walls in Seoul. In case of WWR 20%, the 533.7lux required illumination of offices was not satisfied, whereas the illumination was more than was needed in the case of a WWR of 40%. These results confirmed that shading can avoid excessive daylight and the use of lighting with insufficient illumination by lighting control can saved lighting energy consumption. Figure 4 and Table 5 show the energy consumption by WWR and glazing type and the result of Daylight illumination average.

Figure 4 The Result of CASE1

Table 5 The Result of Simulation by WWR and Glazing type

4.2.2 Comparison of the energy consumption by the installation of shading

The effect of shading on energy consumption was analyzed from the results of CASE 2 with no lighting control. The shading was horizontal exterior shading (60cm). This study compared CASE 2 with CASE 1. This result revealed a 3~14%, 1~9%, 3~16%, and 1~10% decrease in energy consumption at WWR = 20%, 40%, 60% and 80%, respectively. The energy consumption was clearly reduced by applying shading. The BASE and ALT2 of applying 0.6 SHGC showed the minimum energy consumption at WWR = 40%. The ALT1 and ALT3 with an applied 0.4 SHGC showed a minimum energy consumption at WWR = 60%. Therefore, the time of the shading installation should consider the SHGC and WWR.

4.2.3 Comparison of the energy consumption by the Lighting Control

To determine the effect of lighting control on energy consumption, CASE 3 was compared with CASE 1. In the case of lighting control, the energy reduction was 9~13%, 15~19%, 18~21% and 19~23% by window performance at WWR = 20%, 40%, 60% and 80%, respectively. In case of 0.6 SHGC (BASE, ALT2), confirmed minimum energy consumption in WWR 40%. In case of 0.4 SHGC (ALT1, ALT3), the minimum energy consumption was observed at WWR = 60%. Nevertheless, the time of applying lighting control should consider the SHGC and WWR.

4.2.4 Comparison of the energy consumption by the complex application of window elements

CASE 4 was compared with CASE 1 to confirm the energy consumption of the case of applying shading installation and lighting control. The energy consumption reduction was 9~13%, 17~24%, 22~31% and 27~35% at a WWR of 20%, 40%, 60% and 80%, respectively, compared to CASE1. In the case of complex application of window elements (Shading + Lighting Control), this study confirmed that 0.4 SHGC from WWR of 60% and 0.6 SHGC from a WWR of 80% showed the lowest energy consumption.

Table 6 The Energy consumption of Simulation

Overall, this study proposed the Energy Analysis Indicator by the Window Elements in South direction of Seoul. Figure 5 shown the Energy Analysis Indicator. This Energy Analysis Indicator is presented in this study is applicable to the「Energy Star (Homes Builder Option Package)」in U.S,「Approved Document L.」in U.K,「Energy Conservation Regulation (EnEV)」in Germany,「DCGREUH 1999」in Japan and「Energy Conservation Building Code 2007」in India because the element of regulation and guideline is similar to Energy Analysis Indicator. Among them, with the exception of「DCGREUH 1999」in Japan, other regulation and guideline require separate consideration to latitude difference and climate difference. Because「DCGREUH 1999」in Japan is considering to Insulation performance (U-Value) and SHGC by climate zones, if apply to the same climate as South Korea, this Energy Analysis Indicator is useful.

The application of this study was limited to climate that cooling and heating load appears distinctly seasonal climate like a Korea. A similar climate in Central Europe, North America, Northeast Asia can be applied. However, adjustments according to the local climate are needed. And the Energy Analysis Indicator can be used the performance evaluation of new building as well as the window planning of the envelope improvement of existing building.

Figure 5 Energy Analysis Indicator in the South direction of Seoul

5. Conclusions

This study confirmed the complement points of policies and guidelines in Korea by comparing the policies and guidelines in Korea and other countries. The effects of the performance elements of window and architectural/equipment plan elements, were confirmed. This study proposed the Energy Analysis Indicator by the Window Elements in a suitable situation in Korea. The conclusions of this study were as follows:

(1) This study compared the policies and guidelines of Korea and other countries. The performance elements of windows and the architectural/equipment plan elements were determined. The policies and guidelines in Korea in terms of the performance of thermal, air-tightness and WWR were assessed. This study confirmed that any analysis of the energy consumption of buildings needs to consider the complex window elements and energy analysis indicator that complement the problems.

(2) This study confirmed that a high U-Value and low SHGC were conducive to a lower energy consumption in Seoul, east-facing walls in the case of increasing WWR. In case of south-facing walls, energy consumption did not change consistently with the variation of SHGC. The policies and guidelines for windows in Korea proposed a uniform limit and performance regarding the variation of energy consumption. Therefore, the policies and guidelines in Korea need to consider complex elements, such as the orientation, WWR, SHGC and U-Value.

(3) To propose an indicator of a suitable situation in Korea, this study selected a basic window and analyzed the energy consumption according to the window elements. This study also assessed some CASEs by applying shading and lighting control. If shading is installed and lighting control is applied, the WWR showing the minimum energy consumption changed according to the SHGC. If shading is installed and lighting control is applied, 80% WWR has minimum energy consumption at a 0.4 SHGC. Therefore, if applying shading or lighting control was applied, complex elements, such as the WWR and SHGC need to be considered.

ACKNOWLEDGMENT

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Table 1 The Consideration Items of the Policies and Guidelines for Window

Country	No.	Applied target	Insulation Performance	SHGC	VT	WWR	Shading	Lighting control	View	Thermal comfort	Amount of sunshine	Orientation	Air-tightness
U.S	01	Residential	○			○							
	02	Residential /Non- residential							○	○	○		
	03	Non- residential						○	○	○	○		
	04	-	○	○									
	05	Non- residential	○	○	○	○							
U.K	06	Residential	○		○	○							
	07	Residential /Non- residential	○			○							
Germany	08	Residential /Non- residential	○					○					
Canada	09	Residential /Commercial				○	○						
Island	10	Passive House	○		○							○	
Japan	11	Residential	○	○									
India	12	-	○	○									
Korea	13	Residential/ Non-residential	○			○	○					○	○
	14	Residential	○										○
	15	Non-residential	○			○							○
	16	-	○										○
	17	Non-residential	○	○		○	○	○				○	
	18	Residential/ Non-residential	○			○							○
	19	Residential/ Non-residential	○			○					○	○	
	20	Residential	○			○					○		○
	21	Residential/ Non-residential	○			○							
	22	Residential/ Non-residential	○			○	○				○		○

Table 2 Type of Glazing

U-Value \ SHGC	0.2	0.4	0.65	0.75
1.0	Type1	Type6	-	-
1.4	Type2	Type7	-	-
2.1	Type3	Type8	Type11	Type14
2.8	Type4	Type9	Type12	Type15
3.4	Type5	Type10	Type13	Type16

Table 3 Simulation Condition

Section	Contents
Building Type	Office
Floor Area	27 ㎡(6m×4.5m)
Facade Height	2.7m
HVAC	Packaged Single Zone(Psz)
Setpoint	Cooling : 24□ Heating : 21□
Lighting Load	16W/㎡
Equipment Load	10W/㎡
People	3 people
Simulation Period	Annual

Table 4 CASEs and Glazing Type of Simulation

(a) Cases and Condition

CASE	Condition		
	Common	Shading	Lighting Control
CASE 1	Region : Seoul WWR : 20, 40, 60, 80% Orientation : E, W, S, N Glazing system(4 Type)		
CASE 2		●	
CASE 3			●
CASE 4		●	●

(b) Glazing Type in Seoul

Type	U-Value	SHGC
BASE	2.1	0.6
ALT1	2.1	0.4
ALT2	1.4	0.6
ALT3	1.4	0.4

Table 5 The Result of Simulation by WWR and Glazing type

Unit : MJ/㎡·yr (lux)

WWR \ Type	BASE	ALT1	ALT2	ALT3
20%	653.03 (319.10)	653.77 (223.31)	638.64 (265.74)	636.81 (199.25)
40%	661.66 (897.84)	646.21 (627.08)	642.36 (747.03)	615.71 (558.08)
60%	713.91 (1222.06)	656.06 (852.18)	701.77 (1016.08)	619.38 (756.98)
80%	794.62 (1461.33)	687.44 (1017.62)	795.61 (1214.30)	651.71 (902.48)

Table 6 The Energy Consumption of Simulation

Unit : MJ/㎡·yr

WWR \ Type	BASE	ALT1	ALT2	ALT3
20%	653.03	653.77	638.64	636.81
40%	661.66	646.21	642.36	615.71
60%	713.91	656.06	701.77	619.38
80%	794.62	687.44	795.61	651.71
20%+Shading	636.26	653.23	621.07	635.67
40%+Shading	626.12	629.25	600.51	597.82
60%+Shading	639.07	618.37	616.85	579.17
80%+Shading	681.96	624.60	669.32	584.56
20%+L.C	566.49	591.92	555.08	577.91
40%+L.C	544.14	546.16	521.64	513.79
60%+L.C	574.24	537.05	555.73	495.38
80%+L.C	641.13	551.34	635.11	508.95
20%+L.C+Shading	565.10	593.79	553.11	579.30
40%+L.C+Shading	517.85	538.61	490.30	509.27
60%+L.C+Shading	510.20	509.40	480.84	460.77
80%+L.C+Shading	537.60	499.17	516.52	451.18

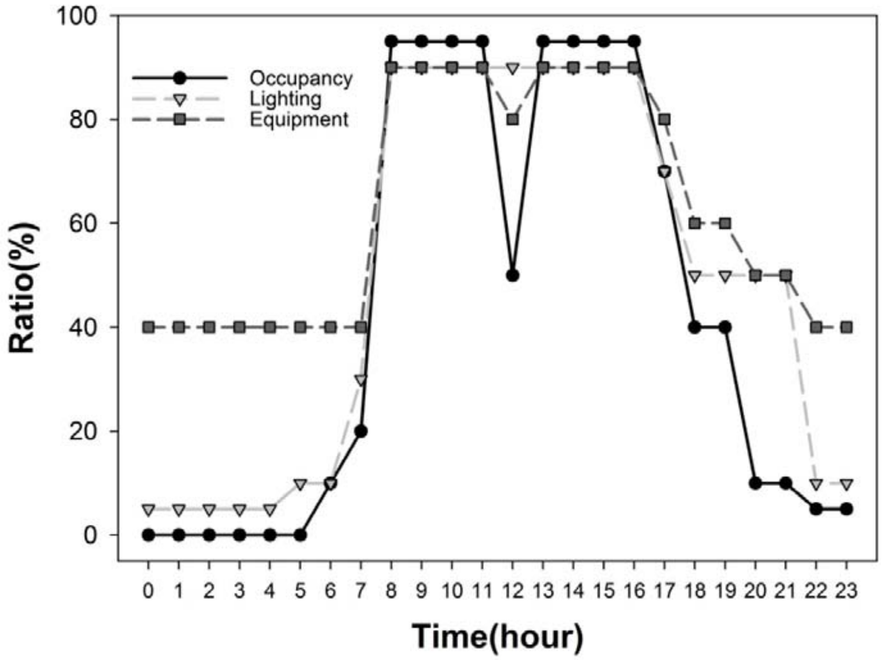
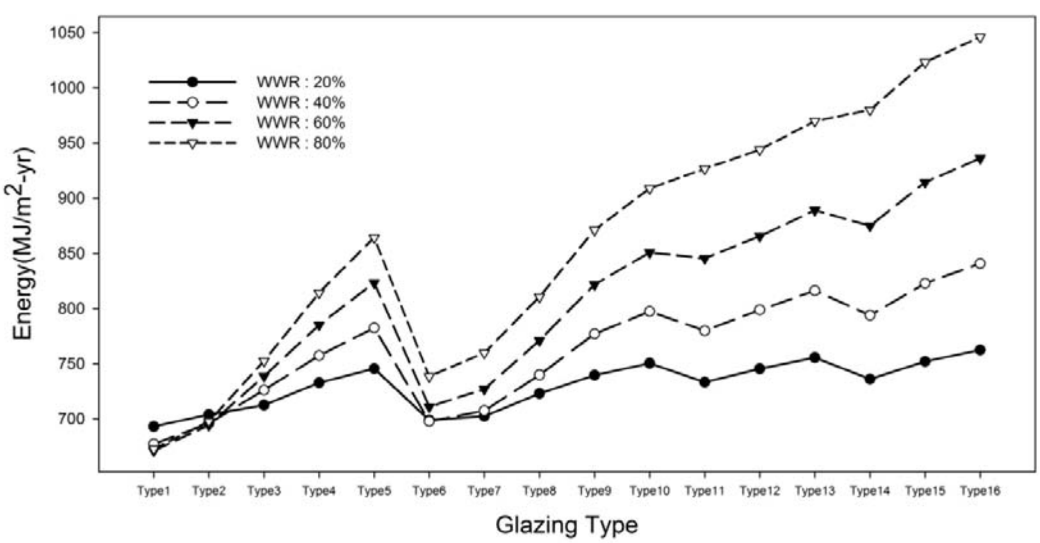
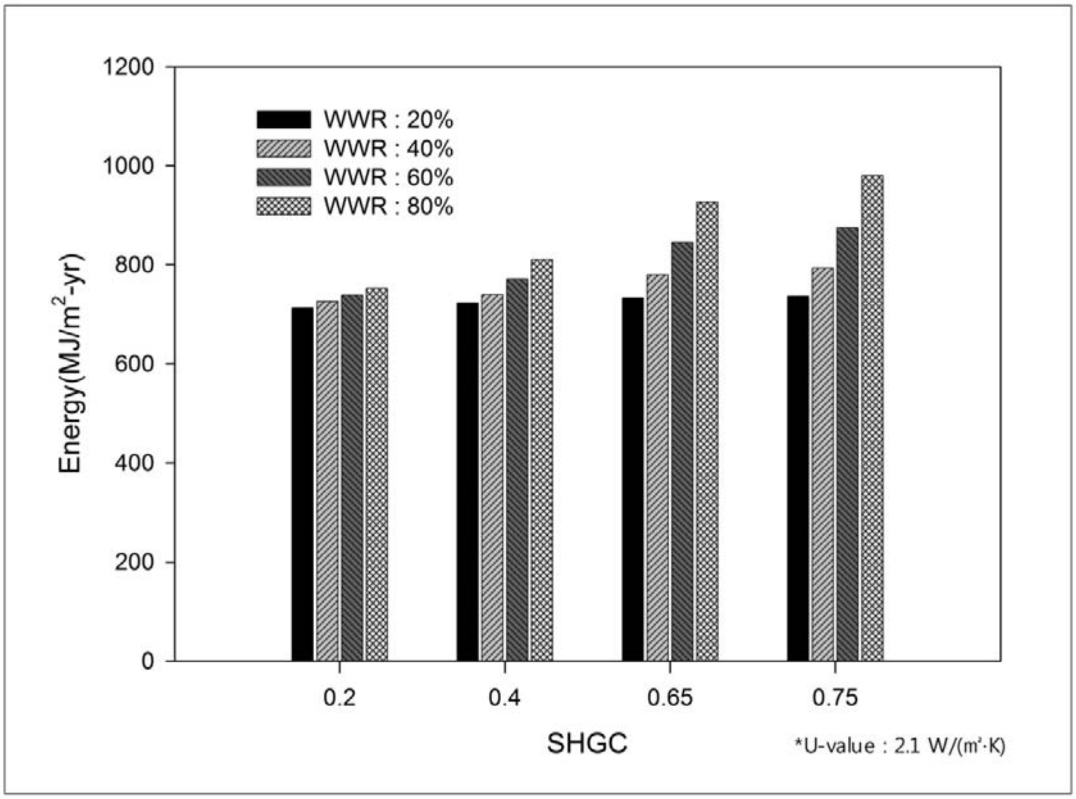


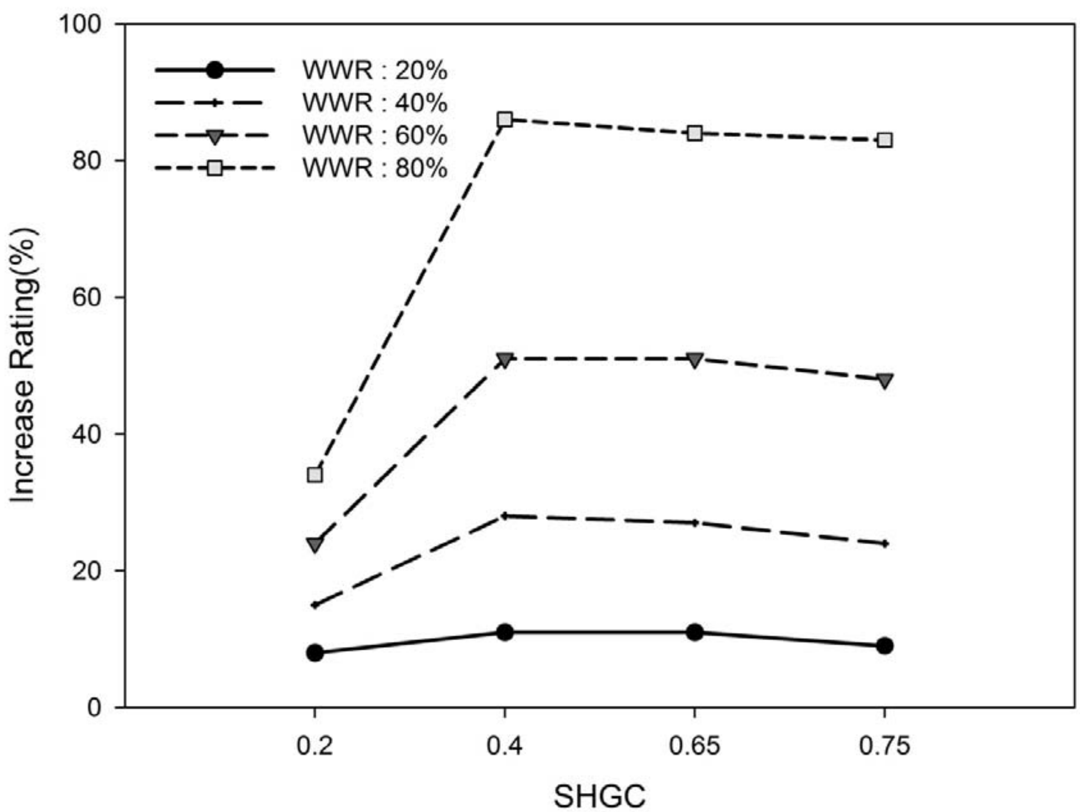
Figure 1 Schedule of simulation



(a) Annual energy consumption

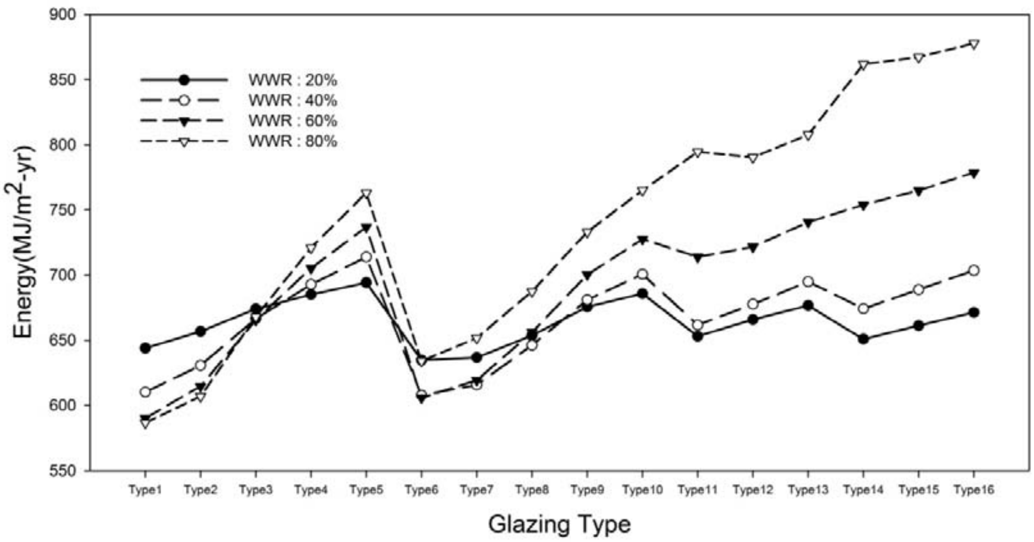


(b) **The variation of energy consumption by WWR and SHGC**

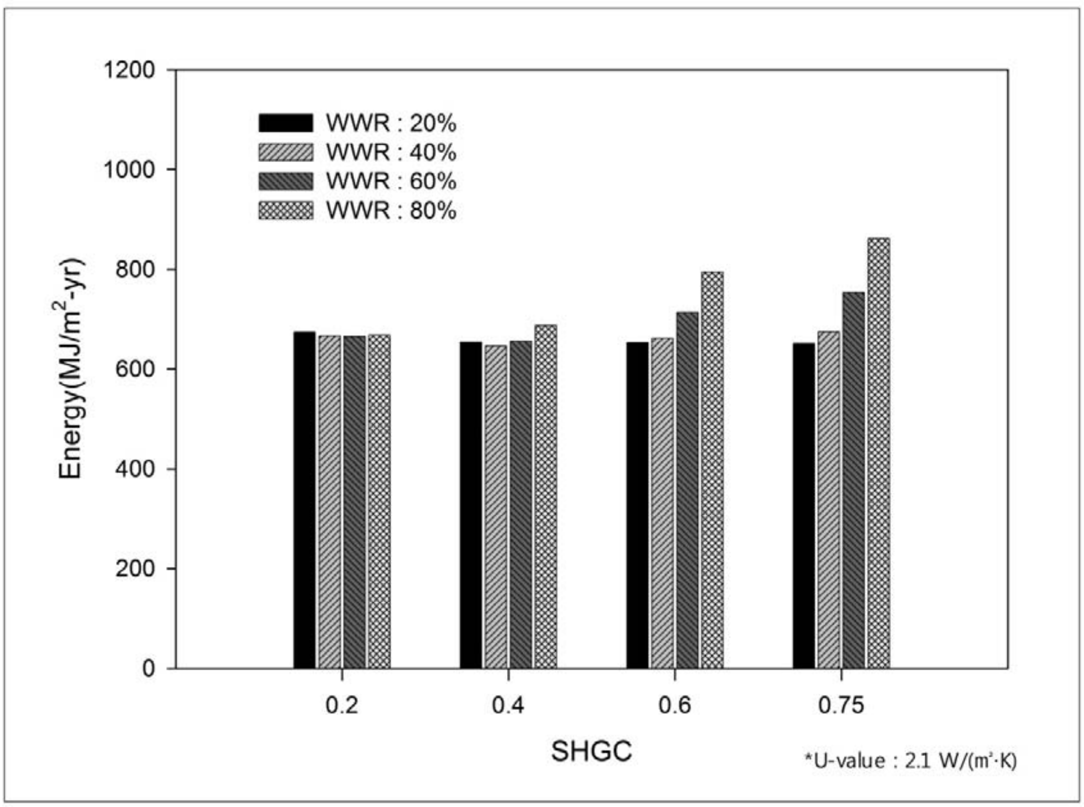


(c) **The rate of increase heating energy**

Figure 2 The result of simulation in East direction of Seoul

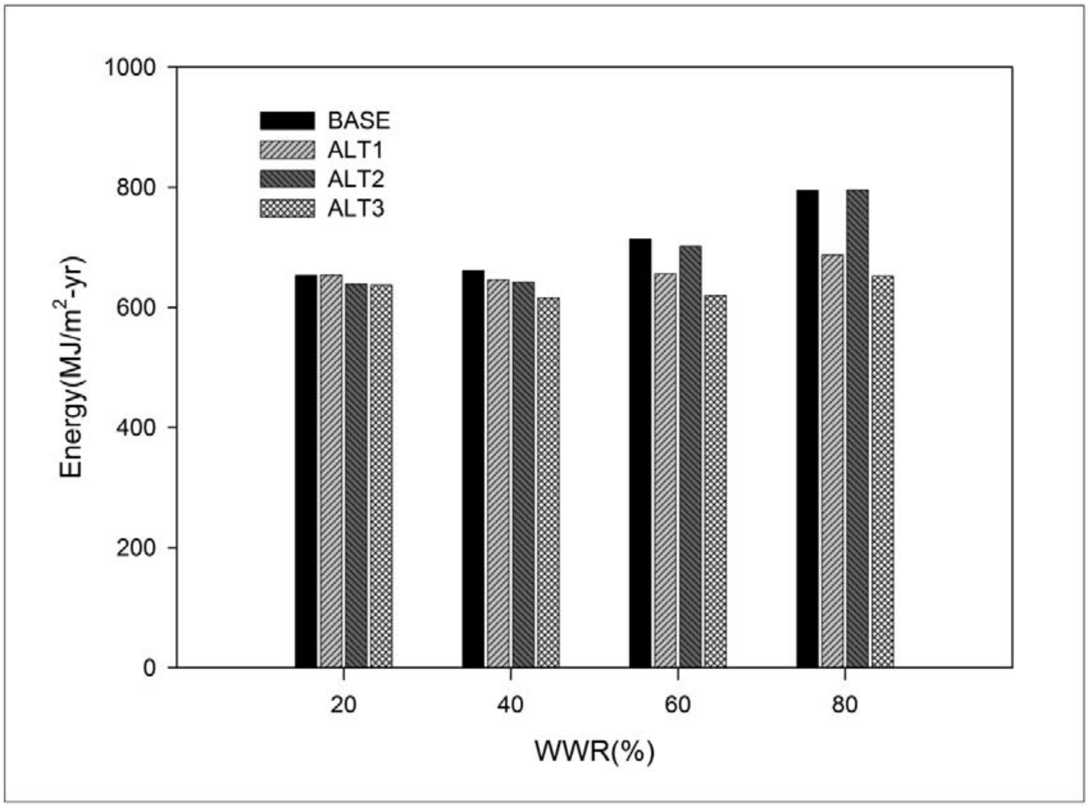


(a) Annual energy consumption

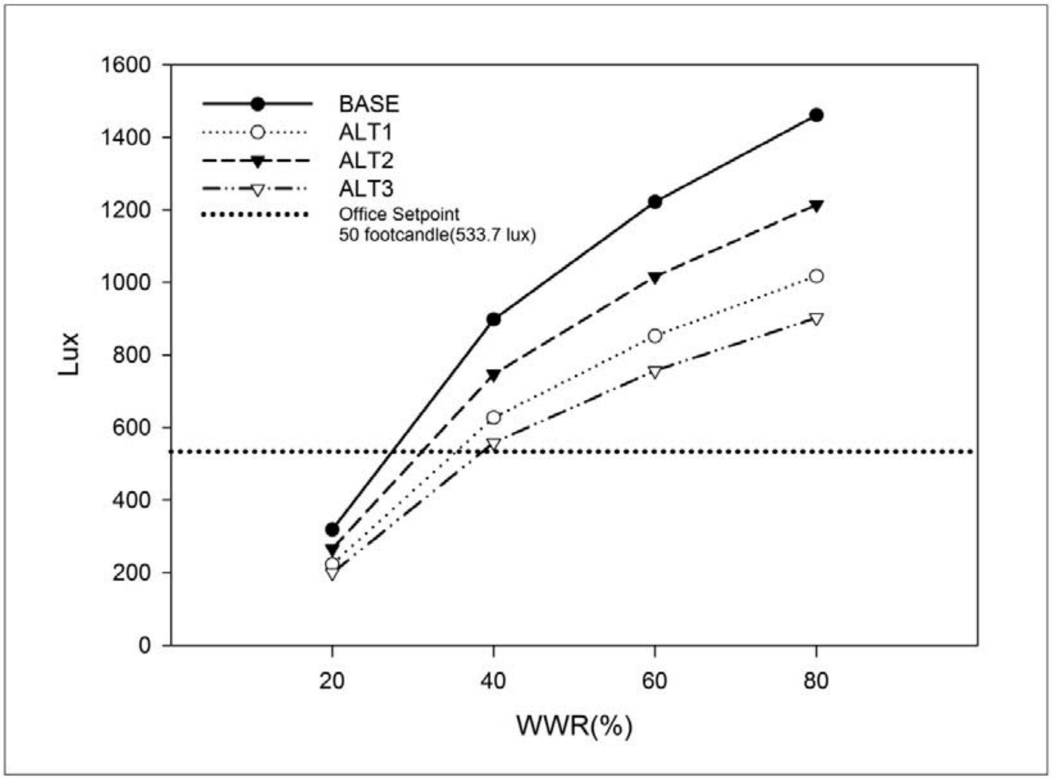


(b) The variation of energy consumption by WWR and SHGC

Figure 3 The result of simulation in South direction of Seoul



(a) Energy consumption by WWR and Glazing type



(b) Daylight illumination Avg. by WWR and Glazing type

Figure 4 The result of CASE1

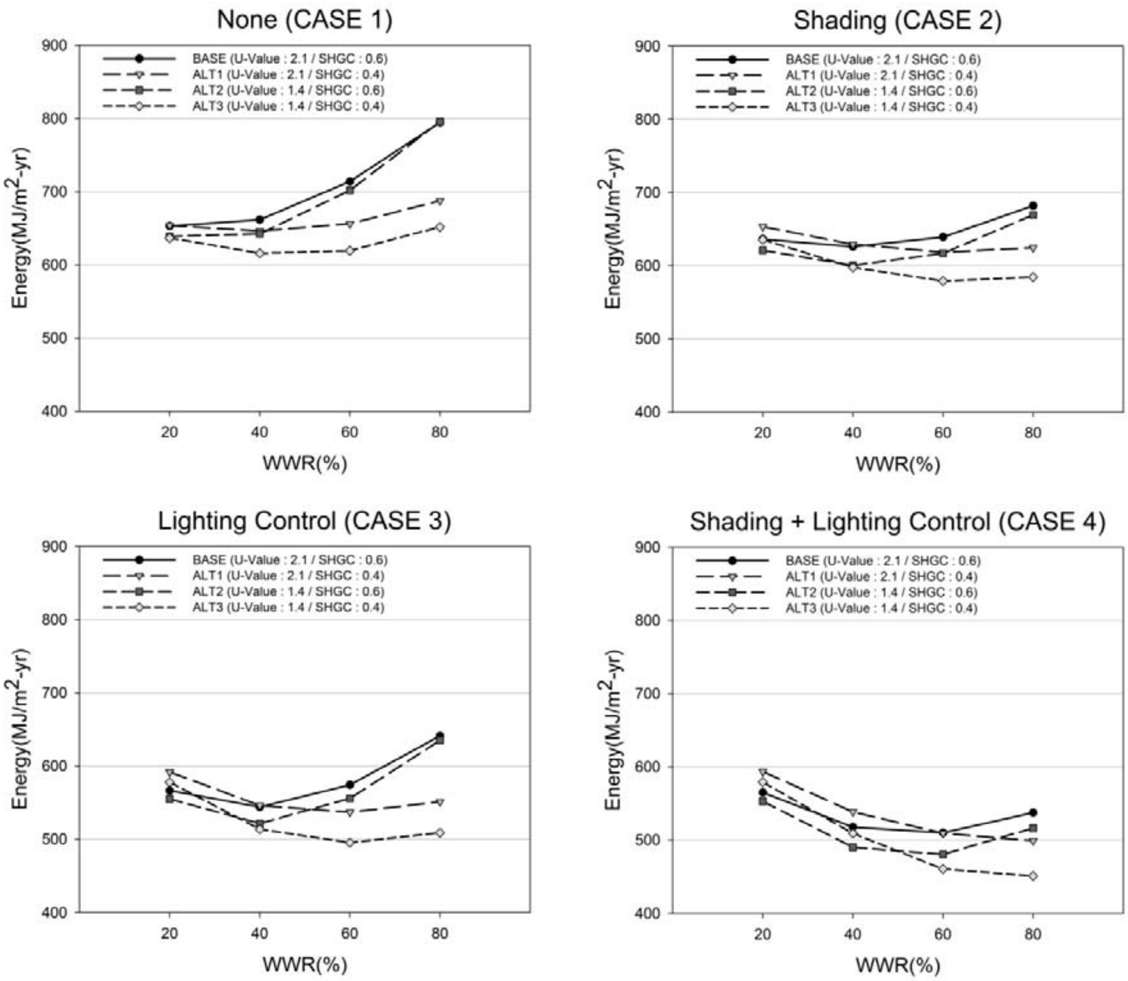


Figure 5 Energy Analysis Indicator in the South direction of Seoul

Highlights

> Compared the policies and guidelines for window in Korea and other country.
>Confirmed the variation of energy consumption by the variation of window elements.
> Proposed the Energy Analysis Indicator for window of a suitable situation in Korea.
[48]